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(54) Title: BREAST BIOPSY AND NEEDLE LOCALIZATION USING TOMOSYNTHESIS SYSTEMS

(57) Abstract: Methods, devices, apparatuses and systems are disclosed for performing mammography, such as utilizing tomosynthesis in combination with breast biopsy.

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Breast Biopsy and Needle Localization using Tomosynthesis Systems

Background and summary of the disclosure

Mammography is a well-established method of breast imaging. Using mammograms of the breast, radiologists identify areas suspicious of pathologies. Further identification, such as the determination of cancer is usually done through the taking of a breast biopsy. This is done in several ways. One way is to use mammography to place a wire or needle into the breast, marking the suspected pathology's location. The patient then undergoes an open surgical procedure, and the surgeon can remove tissue from the suspicious area marked by the wire or needle. This is an open surgical biopsy. Another method is known as stereotactic breast biopsy. In this method, using image guidance, a hollow needle is inserted into the breast, and a tissue sample is taken from the area of interest, without a separate surgical procedure. As stated above both methods require some method of localization of the area of interest and a method to direct a wire or needle into the breast so it resides at the already identified area of interest's location.

This patent disclosure covers methods of wire and/or needle guidance into the breast using breast tomosynthesis imaging technology. It covers both upright and prone biopsy equipment.

Tomosynthesis (tomo) is a method of performing three dimensional (3D) breast x-ray imaging. It generates images of cross sectional slices through a compressed breast, and also is used to identify breast pathologies. One of the advantages of

tomosynthesis is that the images are three-dimensional, so that once an area of interest is identified in an image, its exact 3D coordinate in the breast can be calculated or estimated, e.g. from the x, y coordinate in the image of a slice and from the z, or depth, coordinate given by the image slice depth location. Another advantage of tomosynthesis is its ability to provide high contrast visibility of objects by the suppression of images from objects at different heights in the breast. Because of its superior contrast visibility, it is expected that there will be pathologies seen on the tomo images that will not be visible using standard x-ray mammography or stereotactic devices or using ultrasound or even MRI or other methods currently employed to provide guidance to the insertion of wires and needles to the location of an identified area of interest. For this reason, it is desired to develop localization methods using tomosynthesis systems that utilize tomosynthesis' natural 3D localization abilities.

This patent disclosure addresses both systems and methods for tomosynthesis imaging, and devices and methods for needle and wire localization using tomosynthesis imaging systems. In one non-limiting example, the new approach described in this patent disclosure is based on conventional tomosynthesis designs, e.g. as described in United States Patent Application Serial No. 10/305,480, filed November 27, 2002, United States Patent Application Serial No. 10/723,486, filed November 26, 2003, United States Provisional Patent Application Serial No. 60/628,516, filed November 15, 2004, International PCT Application Serial No. PCT/US2005/0491941, filed November 15, 2005, United States Provisional Patent Application Serial No. 60/631,296, filed November 26, 2004, and International PCT Application Serial No. PCT/US2005/042613, filed November 23, 2005, which are hereby incorporated by reference. Typically, the breast is compressed between a breast platform and a compression paddle. The paddle may be one of the standard paddles used for screening

mammography, or one with holes and guide marks used for needle localization or biopsy procedures with conventional mammography equipment, e.g. as described in U.S. Patent No. 5,078,142 filed November 21, 1989, U.S. Patent No. 5,240,011 filed November 27, 1991, U.S. Patent No. 5,415,169 filed February 17, 1993, U.S. Patent No. 5,735,264 filed June 7, 1995, U.S. Patent No. 5,803,912 filed April 25, 1995, U.S. Patent No. 6,022,325 filed September 4, 1998, U.S. Patent No. 5,289,520 filed October 6, 1992, U.S. Patent No. 5,426,685 filed January 24, 1994, U.S. Patent No. 5,594,769 filed May 9, 1995, and U.S. Patent No. 5,609,152 filed February 15, 1995, which are hereby incorporated by reference, and as used in the prone or upright needle biopsy devices commercially available from the Lorad Division of Hologic, Inc. of Bedford, MA. The x-ray tube is mechanically designed so that it moves along a path that images the breast from differing angles, making a sequence of exposures at differing locations along the path. A digital x-ray image receptor acquires the images. The detector can be stationary during the scan, or it can move during the scan such as if it was mounted on a c-arm connected with the x-ray tube or is otherwise connected to move in sync with the x-ray tube, though not necessarily through the same angle. The entire system can be oriented so that the patient is either upright or lying on a table with her breast pendulant and protruding through a hole in the table and positioned properly on the detector to access the area of interest as needed. One system design would be using a relatively small field of view, such as approximately 5 × 5 cm. This would correspond to developing a tomosynthesis biopsy system with similar field of view to standard prone table stereo localization systems. However, another way disclosed here, which differentiates a tomo biopsy system from conventional stereo localization system, is to use a significantly larger detector field of view. In one example of an embodiment, the field of view can be at least 10 × 10 cm, in another at least 20 × 25 cm, in another

approximately 24 × 29 cm.

Localization of an area of interest can start with breast acquisition carried out in a standard way used in breast tomosynthesis. The data is reconstructed, and reviewed. The area of interest is identified either on the reconstructed images of slices, or in the raw projection images. The 3D coordinates of the area of interest can be computed or estimated from the identification of the area of interest on the images.

Once the 3D location of the area of interest is calculated, known methods of directing needles and wires to that location can be used.

There might be some differences in tomo scans during biopsy procedures from screening mammography. The dose might be higher, to get lower noise images. The angular range might be wider or shallower, and the number of projections might be larger or smaller. One might want a wider angle, for example, to get higher precision depth discrimination. One might also want higher resolution for these scans, compared to conventional tomo screening. This could be accomplished through the use of smaller pixel sizes.

A biopsy system used with a tomosynthesis system can include a needle gun assembly with motorized or non-motorized stage that can direct a needle to a specific 3D coordinate in the breast. This stage may be swung or otherwise moved out of the way of the acquisition system during the initial tomosynthesis scan, so that if desired it does not shadow or interfere with the visualization of the breast or breast area of interest.

Following the tomo scan and the identification of the 3D area of interest location, the stage is moved into place. The needle is moved to the 3D coordinate previously identified. The needle may access in the breast via a left or right lateral access (e.g. with the needle roughly parallel to the compression paddle and the patient's

chest wall), or it could access the breast with the needle roughly normal to the compression paddle, through an opening in the compression paddle. Or, the needle may enter the breast at an angle between the normal and parallel paths (in relation to the compression paddle and detector) through a hole in the breast compression paddle. It may also come from the front of the breast, directing the needle rearwards towards the chest wall. It can also come from between the paddle and the breast platform but at an angle rather than through the hole in the paddle.

The biopsy system should be capable of working with the tomosynthesis system in all orientations of the tomosynthesis system, including, but not limited to, CC, MLO, and ML and LM imaging orientations. These systems can rotate 360° around the breast and take images from any angle.

Standard techniques of breast biopsy typically involve verification of the needle's location before tissue sampling, known as pre- and post-fire verification. In pre-fire, the needle is inserted into the breast approximately 2 cm short of the center of the area of interest and x-ray exposures are made and images are generated and viewed to verify proper pre-fire needle location relative to the area of interest before tissue sampling. In post-fire, at least one additional exposure is made and the resulting image is viewed to verify proper needle location relative to the area of interest after the firing of the needle and before the tissue is sampled.

These verification images can be images from tomosynthesis scans, or they can be stereo x-ray pairs or individual images. The tomosynthesis scans can be done with different angular ranges and different number of projections and a different dose from conventional tomosynthesis imaging.

Post-fire needle verification can be accomplished in a variety of ways, which may depend on whether the needle access was lateral or tangential. One challenge

arises from the fact that the gun and stage and needle are generally radio-opaque and can contribute artifacts to the images if not properly dealt with.

With tangential access, there may be an angular range where the gun and stage shadow the breast. Lateral access may not have the problem of the gun stage in the field of view, but it can have the needle in the field of view, and there might be other mechanics that if imaged can create image artifacts. In general, x-rays from angles that shadow the gun and stage are less useful. Solutions to this problem in accordance with the new approach disclosed in this patent specification include:

a. Development of needle and other sheathing materials that are sufficiently radiolucent that they will not create significant image artifacts. Possible materials are plastics, ceramics, glasses, carbon tubes, and low atomic number metals and other materials. If these materials are used, they can be marked with fiducial markings such as radio-opaque rings or dots allowing visibility in the tomosynthesis images so they can be differentiated from breast tissue or breast area of interest. Alternately, a needle can be used where only the tip (last 1-3 cm) is radiolucent and rest of the needle is radio-opaque.

b. Scanning through angles that do not shadow these objects. This can entail an asymmetric scan geometry, whereby all or an important part of the x-ray beam path does not pass through the needle or other radio-opaque parts. An example is scanning to just one side of the needle.

c. Scanning over a large range, and generally or always avoiding x-ray exposures when the stage or other radio-opaque parts shadow the breast, area of interest or image receptor. Alternatively, x-ray imaging can be done even in angular areas with this shadow problem, but these exposures can be eliminated from viewing or reconstruction, either automatically or through manual elimination

via a user interface. Another alternate method involves artifact suppression algorithms used during reconstruction, as in known in tomosynthesis and CT scanning.

d. Stereotactic imaging. Conventional stereotactic imaging involves using a pair of x-ray images at, for example, ±15° to the normal to the compression paddle. This geometry involves sufficiently large angles to typically avoid the stage shadows on the image receptor. A tomo system can be used to take tomo projection images at angles that avoid undesirable shadows at relevant parts of the images.

e. Scan angle changes. A larger scan angle than used in conventional tomo imaging can better avoid artifacts from the stage.

f. Bringing the needle to a fixed distance from the lesion. An image can then be taken that does not obscure the area of interest, and the proper distance between needle and area of interest can be verified from imaging. The needle can then be advanced into the correct location within the area of interest based on information from the tomo or conventional imaging while the needle is spaced from the area of interest.

g. In many if not most cases the projection images and perhaps the reconstructed images of breast slices will contain at some location an image of the needle. The needle image can create artifacts in reconstructed images, which can be removed via artifact reduction algorithms as in known in conventional tomosynthesis and CT imaging. One algorithm can involve skipping projection images with extensive shadowing in the projections. Another algorithm can involve segmenting out the needle and other high contrast objects and avoiding reconstruction using these pixels, as has been used in CT and other imaging. Other alternatives include viewing the projection images, which can have images of the

needles but no other significant artifacts.

The examples of embodiments disclosed in this patent specification can include user interfaces to mark the area of interest location on either the projection tomo images or the reconstructed tomo images of breast slices. Signals directing the needle to the correct location in the breast can be generated automatically based on identifying the location of the area of interest in the images, or the coordinates of the area of interest can be displayed and the needle can be guided to the appropriate location under manual control.

For the pre and post fire images, a facility can be provided to mark the previously identified area of interest location on the current images. This can help visualization of proper needle placement, in case the area of interest becomes harder to see because it has been removed or in case the needle creates large artifacts. The orientation of the needle relative to this mark can provide assurance as to proper location placement.

The 3D nature of the tomosynthesis images allows for calculation of the 3D volume of the area of interest, once it has been identified on the tomosynthesis projections or reconstructed images of slices. This can be part of the display and used to help verify that the correct lesion has been targeted.

Brief description of the drawings

Figs. 1-5 illustrate various ways of positioning a biopsy needle relative to a breast and imaging positions of an x-ray source and an image plane for reducing undesirable image artifact due to the presence of the needle or other radio-opaque material.

Figs. 6A-6D, 7A-7E, 8A-8E, 9 and 11 illustrate various biopsy sampling needle

designs for reducing undesirable image artifacts.

Fig. 10 shows a block diagram of a system with additional optional features.

Detailed description of examples of preferred embodiments

Fig. 1 illustrates lateral needle access, where a breast compression paddle 10 and a breast support plate 14 can be a part of an otherwise known tomosynthesis system such as described in the co-pending patent applications identified above and incorporated by reference in this patent specification, and a biopsy needle stage 16 and a needle 18 such as used, for example, in the patents identified above that pertain to prone biopsy. For clarity, the rest of the tomosynthesis system and other parts of the biopsy apparatus are not shown in this Fig. 1, and a detailed discussion of the basic aspects of tomosynthesis is not included herein. The reader is referred to the references cited herein for such discussions. For example, image reconstruction can be performed using filtered back projection (for rapid speed of reconstruction) and/or artifact reduction methods (such as ordered statistics backprojection), as disclosed, for example, in U.S. Patent Application Publication No. 2002/0113681, the entire contents of which are incorporated by reference herein.

A patient's breast 12 is compressed between paddle 10 and support plate 14 and a needle biopsy stage 16 has been used to position the tip of a biopsy needle 18 near an area of interest 20 in breast 12. In this example needle 18 enters the breast 12 generally laterally, i.e. along the plane of support plate 14 and along the chest wall of the patient, and from the left as seen in the drawing. Of course, the needle 18 can enter instead from the right, and need not be exactly parallel to support plate 14 or to the chest wall, but can be at any angle thereto that the health professional doing the needle biopsy finds suitable for the particular patient or area of interest location. As described above,

the location of area of interest 20 has been determined based on tomosynthesis images that can be tomo projection images and/or tomo reconstructed slice images. In Fig. 1, the patient's chest is behind the illustrated structure and is generally along the plane of the sheet. If upright biopsy is used, the patient's chest wall would be generally vertical; if a prone biopsy table is used, the patient's chest wall would be generally horizontal.

Fig. 2 illustrates frontal needle access in which needle 18 accesses area of interest 20 from the front of breast 12, in a direction generally along the plane of support plate 14 and normal to chest wall 22 of the patient. Again, the needle 18 direction need not be exactly parallel to support plate 14 or normal to chest wall 22, but can be at any convenient angle thereto that would allow the tip of needle 18 to reach area of interest 20 generally from the front of the breast 12, at either side of the nipple. In Fig. 2 the patient's chest wall 22 is generally normal to the sheet.

Fig. 3a illustrates tangential needle access, where a breast compression paddle 10 has, as seen in Fig. 3b, one or more needle access holes 11. Fig. 3a illustrates breast compression paddle 10, breast 12 and support plate 14 in a view similar to that of Fig. 1, but a needle stage 16 and needle 18 at a position above the breast. Needle 18 accesses area of interest 20 in a direction generally normal to support plate 14 and along the chest wall (not shown) of the patient. Again, needle 18 need not be at the angles shown but may be at any angle that the health professional doing the biopsy finds suitable.

Fig. 4 illustrates one type of a tomo scan that can be used to reduce undesirable image artifacts due to the presence of a biopsy needle 18 and possibly other radio-opaque materials. While Fig. 4 illustrates tangential needle access similar to that of Fig. 3, the principles discussed below in connection with Figs. 4 and 5 apply to any other type of access to area of interest 20. Fig. 4 illustrates positions 24a, 24b, ..., 24n

of an x-ray tube (not shown) from which the tube emits x-ray beams for taking tomo projection images. While positions 24a-24n are illustrated as being along an arcuate path, they can be along a differently shaped path, and scanning can start from either end of the path, or from an intermediate positions along the path. As evident from Fig. 4, it is likely that at some positions of the scan, needle stage 16 would obscure at least a significant part of the imaging x-ray beam and the resulting projection image is likely to have significant and probably unacceptable artifacts.

Fig. 5 is otherwise similar to Fig. 4 but illustrates a gap region 26 in the path of x-ray tube positions 24a-24n. No x-ray tomo exposures are taken from positions in this gap region 26. Exposures are taken from positions outside this region to minimize or at least significantly reduce the extent to which the needle stage 16 and any other x-ray opaque materials affect the imaging x-ray beams and thus reduce undesirable artifacts in the images relative to images that could have been obtained with exposures taken from positions in gap 26. Sufficient tomo projection images can be taken from positions outside gap 26 from which acceptable tomo reconstructed images of breast slices can be computed to localize needle 18 relative to area of interest 20. Gap 26 can be at an end of the path of positions 24a-24n or it can be intermediate positions 24a-24n. Different x-ray dose can be used for different ones of positions 24a-24n, e.g. less dose for exposure positions in which radio-opaque materials in the path of the x-ray beam are likely to generate more undesirable artifacts, and greater dose for positions in which such material are less likely to produce such artifacts. It is possible to take exposures even from positions in gap 26, preferably at low x-ray dose, but not use the resulting projection images for reconstructing tomo images of breast slices.

During the x-ray tomo exposure, metallic breast biopsy needles can obstruct the sampled lesion or cause other undesirable artifacts such as, for example, streaking

artifacts in reconstructed tomosynthesis images. This is especially acute where the sampled lesions are calcifications. This obstruction can reduce the accuracy of biopsy. Embodiments of the present disclosure include a needle design that allows for better visibility of the sampled lesion.

Several embodiments of such needles are shown in Figures 6-8. Here, x-ray transparent material is used in the construction of the stem of the needle to a significant extent so the sampled lesions can be seen more clearly when imaged with tomosynthesis or 2D mammography. The needle stem should still be solid enough to cut the tissue and the lesion. Of course, the x-ray transparent material need not be perfectly transparent but only sufficiently transparent to minimize or at least significantly reduce undesired image artifacts as compared with the use of metallic needles without such material. The term "x-ray transparent" is used in this sense in this patent disclosure.

Figures 6A-6D illustrates the use of a breast biopsy needle with an x-ray transparent body according to embodiments of the present disclosure. The needle 30 consists of two metallic tips 32 for cutting the tissue and lesion 38, and two needle stems 34 made of x-ray transparent material so as not to block x-rays. Because the needle stems 34 are x-ray transparent, the position of the needles may be determined by the position of the needle tips 32 in x-ray images and the known needle geometry. Fig. 6A illustrates the needle 30 prior to its firing, The relative location of the needle and the lesion 38 are confirmed using x-ray tomosynthesis (or 2D x-ray mammography). Fig. 6B illustrates that one of the two needle stems 34 may have a notch 36. The notched needle stem 34a may be within the lumen or cannula of the un-notched needle stem 34b. The notched needle stem 34a may be fired from the un-notched needle stem 34b such that the notch is placed in proximity to the lesion 38. Fig. 6C illustrates that

the un-notched stem 34b may be pushed to close around the notched stem 34a thereby cutting and trapping the lesion 38, or at least a part thereof, within the notch 36 and the cannula of the un-notched stem 34b. Tomosynthesis or 2D mammography may then be used to confirm the position of the lesion 38 within the notch 36 and the cannula of the un-notched stem 34b. Fig. 6D illustrates that the needle may be removed from the patient with the trapped lesion 38. Tomosynthesis or 2D mammography may then be used to confirm that the lesion 38 has been correctly sampled.

Figures 7A-7E illustrate the use of a breast biopsy needle with an x-ray transparent body stiffened with metal according to another embodiment of the present disclosure. The needle 40 comprises two metallic tips 42 (to cut the tissue and lesion 48), and two needle stems 44 made of x-ray transparent material (so as not to block or scatter x-rays excessively) and removable solid metallic wires or ribs 50 to enhance the structural integrity of the needle stems during the firing. The wires or ribs 50 can be removed from the stems, after firing, to allow the needle stems 44 to be x-ray transparent and the taking of x-ray images after the wires or ribs 50 have been withdrawn. As seen in Fig. 7A, before firing the needle 40, the relative location of the needle 40 and the lesion 48 may be confirmed using tomosynthesis or 2D mammography. As seen in Fig. 7B, a notched needle stem 44a may be fired from an un-notched needle stem 44b. As seen in Fig. 7C, the un-notched needle stem 44b may be pushed to the notched needle stem 44a so as to cut and trap the lesion 48 between the notch 46 of the notched needle stem 44a and the un-notched needle stem 44b. As seen in Fig. 7D, the metallic wires 50 can be removed form the needle stems 44 prior to performing tomosynthesis or 2D mammography to confirm the location of the lesion 48. As seen in Fig. 7E, the needle 40 may be removed from the patient with the trapped lesion 48. Tomosynthesis or 2D mammography may then be used to confirm

that the lesion 48 has been correctly sampled.

Figures 8A-8E illustrate another embodiment of a new breast biopsy needle that comprises two coaxial bodies each having an x-ray transparent (e.g. plastic) layer and an x-ray opaque (e.g. metal) layer that adds mechanical strength or stiffness but can be withdrawn, if desired, after the needle is in place in the breast but before x-ray images are taken. As seen in Fig. 8A, needle 60 is inserted into the breast until its cutting tips 62 are close to but spaced from suspected lesion 68. At this time, the relative locations of the needle and the lesion can be confirmed by taking tomosynthesis or 2d mammography images. Then, as seen in Fig. 8B, the notched stylet 64b (the notch shown as 66) of the needle can be fired into lesion 68 to sample it and, as seen in Fig. 8C the cannula 64a can be pushed in to slice the lesion or at least a part of it into the notch. Then the radio-opaque metal layers can be withdrawn from each of the cannula and the stylet to leave the x-ray transparent structure seen in Fig. 8D (except for its cutting tips 62). At this time, post-fire tomosynthesis or 2D mammography images can be taken to confirm that the lesion or a part of it is in the notch. Because of the use of x-ray transparent material at the lesion at this time, the post-fire images are unlikely to suffer from undesirable artifacts. The core system can then be pulled back with the lesion sample, e.g. to the position illustrated in Fig. 8E.

Figure 9 illustrate another example of a new breast biopsy needle. Biopsy needle 90 is configured as "tube-within-a-tube" cutting device and includes an outer cannula 91, an inner cannula (or localizing obturator) 92, an introducer stylet 93 and an introducer sheath 94. In addition, the outer cannula 91, localizing obturator 92, introducer stylet 93 and introducer sheath 94 can be mounted to a handpiece (not shown) or an attachment (not shown) which is in turn coupled to a support fixture or positioning device for moving the biopsy needle to a desired position. The outer

cannula 91 defines an outer lumen and terminates in a tip which is preferably a trocar tip that can be used to penetrate the patient's skin. The localizing obturator 92 fits concentrically within the outer cannula 91. The localizing obturator 92 can be driven by a rotary motor and a reciprocating motor drive to translate the localizing obturator 92 axially within the outer cannula 91, while rotating the localizing obturator 92 about its longitudinal axis (or the localizing obturator 92 can be rotated and/or translated manually). Alternatively, the introducer stylet 93 which is inserted in the annular introducer sheath 94 can be inserted. In this example, the introducer stylet 93 and/or sheath 94 can be radiolucent with a radio-opaque band at a distal end thereof.

Additional examples of breast biopsy needles are disclosed in U.S. Patents Nos. 6,638,235, 6,758,824, 6,620,111 and 6,626,849 and U.S. Publications Nos. 2006/0155209 A1, 2006/0129062 A1, 2006/0030784 A1, 2005/0113715 A1, 2005/0049521 A1, and 2004/0267157 A1, the entire contents of which are incorporated herein by reference.

Thus, in one aspect this patent specification discloses a method and a system in which tomosynthesis reconstructed images of slices of a patient's breast and/or tomosynthesis projection images of the breast are used to (1) identify the location of a suspected area of interest in the breast, (2) guide needle biopsy of the area of interest, (3) confirm pre-fire position of the needle relative to the area of interest, and/or (4) confirm post-fire position of the needle relative to the area of interest. One unique benefit of this approach is with respect to suspected pathologies that can be seen or assessed better in tomosynthesis images than in conventional mammograms or in conventional ultrasound images of breast tissue. The method and system involve taking a series of tomosynthesis projection images at respective different angles of the imaging x-ray beam relative to the breast, for example in the manner disclosed in said

patent applications that are incorporated by reference in this patent specification. The information from these projection images is reconstructed into images of slices through the breast, which may represent slices of selected thickness and selected angles relative to the breast platform or the imaging plane(s) of the projection images. Typically but not necessarily the reconstructed images represent slices that are parallel to the breast platform and thus to the plane of a conventional mammogram. These images are used to identify the location of the area of interest in the breast in three dimensions, for example by having the health professional point to the location of the area of interest in one or more images and using the system to compute the 3D coordinates of the location in a manner similar to that used in said biopsy system patents identified above and incorporated by reference in this patent specification, or in a different manner, such as by pointing to the area of interest in a reconstructed slice image to thereby identify the location of the area of interest in two dimensions in the plane of the slice and to provide the third dimension from knowledge of the depth of the slice in the breast. This 3D information of the area of interest location can be used together with information regarding a geometrical relationship between the equipment in which the breast of compressed and immobilized to determine the direction and extent of biopsy needle motion executed by a needle stage in a manner similar to that disclosed in said patents incorporated by reference herein, to position the needle, to sample the area of interest and to confirm pre-fire and post-fire locations of the needle relative to the area of interest.

In order to reduce undesirable artifacts in the x-ray images due to the presence of radio-opaque objects such as the biopsy needle in the imaging x-ray beam, the method and system disclosed here employ new approaches either singly or in combinations or subcombinations with each other. A first new approach in this respect

pertains to selection of tomosynthesis images and involves taking projection tomosynthesis images only at angles in which the radio-opaque objects are not in the imaging x-ray beam or, if they are in the beam, their effect in the image is significantly less than it would have been for other possible beam angles. This may involve not taking projection images at angles that would produce more undesirable artifacts and/or taking such projection images but not using them in reconstructing slice images. A second new approach that can be used instead of or in addition to the first one is to carry out post-processing of the tomo images to reduce artifact therein due to the presence of radio-opaque objects in the beam. This can involve processing of the reconstructed slice image, e.g. by using streak artifact removal algorithms similar to those conventionally used in CT (computerized tomography) technology, and/or image processing of the tomo projection images to remove or reduce such artifacts. A third new approach that can be used instead of one or more of the first and second, or together with one or both of the first and second, is to use biopsy equipment that reduces or avoids such image artifacts, e.g. a biopsy needle that is made at least partly of a material that is significantly more x-ray transparent than conventional biopsy needles. A needle made of such material can be used as is for insertion into the breast and for tissue sampling, or it may be stiffened by portions of an x-ray opaque material such as metal that are used for insertion and/or tissue sampling but are withdrawn from the breast or at least from the immediate vicinity of the area of interest before pre-fire and/or post-fire x-ray images can be taken to thereby avoid the image artifacts that such metal would cause if not withdrawn. As one example, such stiffening portions can be in the form of pins or ribs inside a cannula. As another example, they can be sleeves coaxial with a cannula and/or a stylet. Other examples of stiffening portions that are withdrawn before pre-fire and/or post fire imaging also are contemplated.

Additional features can be added. For example, in the system 100 shown in Fig. 10, a calcification detector 104 is added in a sample delivery path 103 between a biopsy needle 101 and a collection chamber (or filter) 102. The sample delivery path 103 typically includes a tube or other channel for delivery of the extracted sample to the collection filter 102. The calcification detector 104 can be coupled to the sample delivery path 103 to determine whether the samples include calcifications and estimate an amount of the calcifications. The calcification detector 104 can include, as an example, an x-ray source and detector for imaging the samples passing through the sample delivery path 103, and a CAD (computer aided diagnosis) component configured to detect and count the number of calcifications in the samples.

In one example (Fig. 11), a tissue biopsy apparatus 110 configured as a handheld device (although the apparatus can also be mounted to a support fixture that is used to position the biopsy needle) includes a biopsy needle mounted to a handpiece. The biopsy needle includes an outer cannula 115 terminating in a tip 116. A tissue-receiving opening 125 is provided (relatively) near the tip 116. An inner cannula 117 fits concentrically within the outer lumen of the outer cannula 115. The inner cannula 117 is rotated (for example, by a rotary motor) about its longitudinal axis and is translated axially within the outer cannula 115 (for example, by a reciprocating motor drive). The outer cannula 115 terminating, tip 116, inner cannula 117 and tissue-receiving opening 125 interoperate similar to the other examples discussed above to extract biopsy samples of a patient's breast. The inner cannula 117 provides an avenue for aspiration of the biopsy samples to the tissue aspiration path which also includes aspiration tube 150 coupling the tissue aspiration path to a collection chamber 155. Aspirator 121 applied vacuum or aspiration pressure to the collection chamber to draw samples through the tissue aspiration path to the collection chamber 155. X-ray tube

111 and detector 112 operate under appropriate control of a controller 114, and a detection signal representing the x-rays received by the detector 112 from the source 111 is output to CAD component 113 which decodes the signal to determine whether the samples include calcifications and estimates an amount of the calcifications. CAD systems and techniques are well-known in the art, and therefore a detailed discussion of such systems and techniques is omitted from this disclosure in the interest of clarity and brevity.

In the case that the collection filter is integrated with the biopsy needle in a handheld device or in a needle stage, the x-ray tube and detector would be small-scaled. An example of a small scale detector is available from Hamamatsu, Corporation, Bridgewater, New Jersey (see http://sales.hamamatsu.com/en/products/electron-tube-division/x-ray-products/x-ray-flat-panel-sensor.php). Information regarding a small scale x-ray tube (40 kV metal-ceramic X-ray tube from Newton Scientific Inc., Cambridge, Massachusetts) is available at http://www.newtonscientificinc.com/swans.htm.

In addition, an additional line 106 can be added for introducing anesthetic and/or contrast agents, for example, along with a flushing agent or lavage. The introduction of the anesthetic and/or contrast agents can be automated and synchronized to the imaging sequence.

Many variations can be introduced on the above-discussed illustrative embodiments and examples without departing from the spirit of the disclosure or from the scope of the appended claims. For example, elements and/or features of different examples and illustrative embodiments may be combined with each other and/or substituted for each other within the scope of this disclosure and appended claims.

This application claims the priority of U.S. Provisional Application Serial No.

60/774,142, filed February 15, 2006, the entire contents of which are incorporated by reference herein.

What is claimed is:

1. A system for facilitating biopsy needle localization utilizing tomosynthesis imaging of a patient's breast comprising:

an x-ray source;

tomosynthesis image reconstruction means, including x-ray image receptor, configured to reconstruct tomosynthesis images of the patient's breast based on x-rays received by said x-ray image receptor from said x-ray source and passed through the patient's breast during tomosynthesis scans;

user interface configured to display said tomosynthesis images, receive identification of an area of interest in the patient's breast, and determine three-dimensional coordinates of the identified area of interest; and

a tomosynthesis controller configured to control said x-ray source and x-ray image receptor for said tomosynthesis scans;

a needle assembly including a biopsy needle,

wherein said biopsy needle is positioned based on said three-dimensional coordinates of said area of interest.

2. The system of claim 1, wherein said tomosynthesis controller controls said x-ray source and x-ray image receptor to perform a plurality of additional tomosynthesis scans at respective angles, and for each of said additional tomosynthesis scans at the respective angles, the needle assembly is positioned to avoid casting a shadow in said area of interest during said tomosynthesis scans.

3. The system of claim 1, wherein said identification of the area of interest in the patient's breast is recorded as a mark on the tomosynthesis images, and the mark is

automatically placed at a corresponding location on one or more subsequent images of the patient's breast.

4. The system of claim 1, wherein said tomosynthesis controller controls said x-ray source and tomosynthesis image reconstruction means to obtain one or more pre-fire images of the patient's breast for verifying needle location relative to said area of interest, prior to firing of said biopsy needle.

5. The system of claim 1, wherein said tomosynthesis controller controls said x-ray source and tomosynthesis image reconstruction means to obtain a post-fire image for verifying proper needle location, after firing of said biopsy needle and before tissue of the patient's breast is sampled.

6. The system of claim 1, wherein the biopsy needle is substantially radiolucent, with the needle tip being radio-opaque.

7. The system of claim 1, wherein the needle assembly further includes an introducer, and the introducer is radiolucent, with a radio opaque band at a distant end of the introducer.

8. The system of claim 1, wherein a body of the needle assembly is radiolucent, with the needle tip being radio-opaque.

9. The system of claim 1 further comprising:

a positioning device coupled to said needle assembly to move said needle assembly; and

a biopsy controller,

wherein said positioning device is motorized, and said biopsy controller controls said motorized positioning device to move said needle assembly to a specific position based on said three-dimensional coordinates determined by said user interface.

10. The system of claim 9, wherein said biopsy controller controls said motorized positioning device to move said needle assembly prior to an initial one of said tomosynthesis scans, to a non-interfering position where the needle assembly does not cast a shadow in said area of interest during said tomosynthesis scans.

11. The system of claim 1, wherein said three-dimensional coordinates of said area of interest is displayed via said user interface, and needle tip coordinates are dynamically displaying via said user interface as the biopsy needle is manually positioned.

12. The system of claim 1 further comprising:

a positioning device coupled to said needle assembly to move said needle assembly,

wherein an operator manually positions the needle assembly utilizing the positioning device.

13. The system of claim 12 further comprising:

a positioning device coupled to said needle assembly to move said needle assembly; and

a hand-operated device coupled mechanically or electrically to said positioning device,

wherein an operator manually operates said hand-operated device to control the positioning device to position the needle assembly.

14. The system of claim 1 further comprising:

a collection chamber configured to collect samples obtained by the biopsy needle; and

an automated calcification detector in a sample delivery path between said biopsy needle and said collection chamber,

wherein said automated calcification detector determines whether the samples include calcifications.

15. The system of claim 14, wherein said automated calcification detector estimates an amount of said calcifications.

16. The system of claim 1 further comprising:

an additional line coupled to the needle assembly for introducing anesthetic and/or contrast agents,

wherein the introduction of the anesthetic and/or contrast agents is synchronized to the imaging sequence.

17. The system of claim 1, wherein the image reconstruction is performed using filtered back projection.

18. The system of claim 1, wherein the image reconstruction uses artifact reduction methods.

19. A method for needle localization for breast biopsy, said method comprising the steps of:

(a) performing tomosynthesis scans of a patient's breast, and obtaining data from said tomosynthesis scans;

(b) displaying tomosynthesis images of the patient's breast based on said data obtained in step (a);

(c) receiving an indication on said tomosynthesis images of an area of interest in said patient's breast, and determining three-dimensional coordinates of said area of interest;

(d) positioning a biopsy needle based on said three-dimensional coordinates of said area of interest determined in step (c).

20. The method of claim 19, further comprising:

positioning said biopsy needle prior to step (a) at a non-interfering position where the biopsy needle does not cast a shadow in said area of interest during said tomosynthesis scans.

21. The method of claim 20, further comprising:

positioning said biopsy needle with a motorized stage prior to step (a), in order to avoid casting a shadow in said area of interest during said tomosynthesis scans.

22. The method of claim 19, further comprising:

(e) inserting said biopsy needle into the patient's breast after step (d);

(f) applying X-ray exposures to obtain one or more pre-fire images of the patient's breast for verifying needle location relative to said area of interest determined in step (e);

(g) firing said biopsy needle, after verifying the needle location using the one or more X-ray images obtained in step (f); and

(h) applying at least one additional exposure and obtaining a post-fire image for verifying proper needle location, after step (g) and before tissue of the patient's breast is sampled.

23. The method of claim 22, further comprising:

recording said indication of the area of interest in the patient's breast as a mark on the tomosynthesis images.

24. The method of claim 23, further comprising:

placing the mark at a corresponding location on at least one of one or more pre-fire images and post-fire image of the patient's breast.

25. The method of claim 19, wherein said tomosynthesis scans are performed in step (a) at respective angles, and for each tomosynthesis scan at the corresponding angle, image acquisition is not shadowed or interfered by the biopsy needle.

26. The method of claim 19, further comprising:

allowing the biopsy needle to be positioned at a test position a selected distance from the area of interest;

performing a scan of the patient's breast with the biopsy needle positioned at the selected distance from the area of interest, and generating an image based on data acquired from said scan;

indexing the biopsy needle from said test position to a specific position within the area of interest, after receiving confirmation that the area of interest is not obscured by the biopsy needle in the image, and performing at least one additional scan.

27. The method of claim 19, further comprising:

displaying said three-dimensional coordinates of said area of interest;

allowing the biopsy needle to be manually positioned; and

dynamically displaying needle tip coordinates as the biopsy needle is manually positioned.

28. The method of claim 19, further comprising:

determining a volume of said area of interest; and

displaying said volume of said area of interest.

29. The method of claim 19, where the needle positioning in step (d) is via a motorized mechanism.

30. The method of claim 19, wherein the needle positioning in step (d) is performed manually.

31. The method of claim 19, wherein the needle positioning in step (d) is performed by manually operating an hand-operated device.

32. An apparatus for performing breast biopsy, comprising:

a biopsy needle configured to obtain samples of a patient's breast;

a collection chamber coupled to the biopsy needle via a sample delivery path; and

a calcification detector coupled to the sample delivery path to determine whether the samples include calcifications and estimate an amount of the calcifications.

Fig. 1

System showing side lateral needle access to area of interest

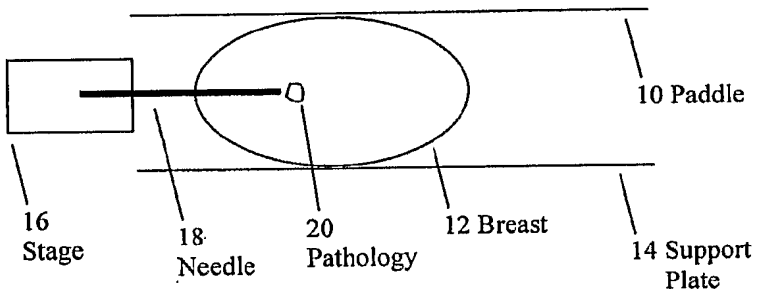
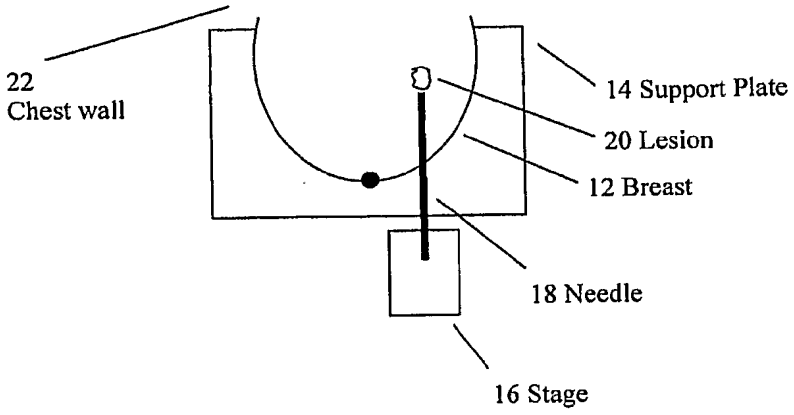


Fig. 2
System showing front needle access to area of interest



System showing tangential needle access, and opening in compression paddle to allow needle to enter the breast

Fig. 3A

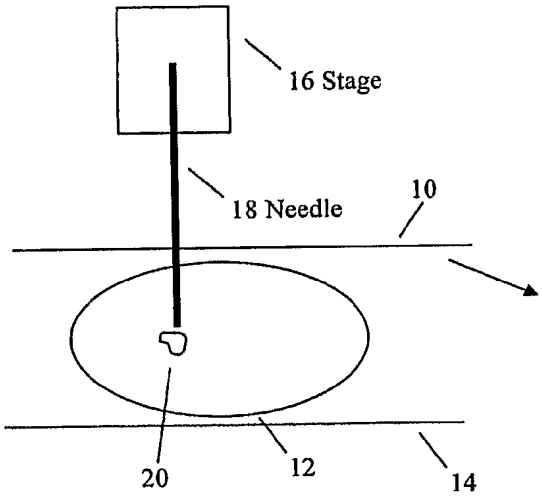


Fig. 3B
Paddle with access hole

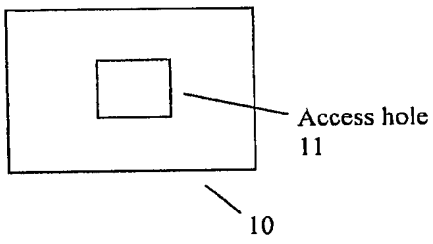


Fig. 4
System showing asymmetric tomo scan to avoid shadowing the gun stage

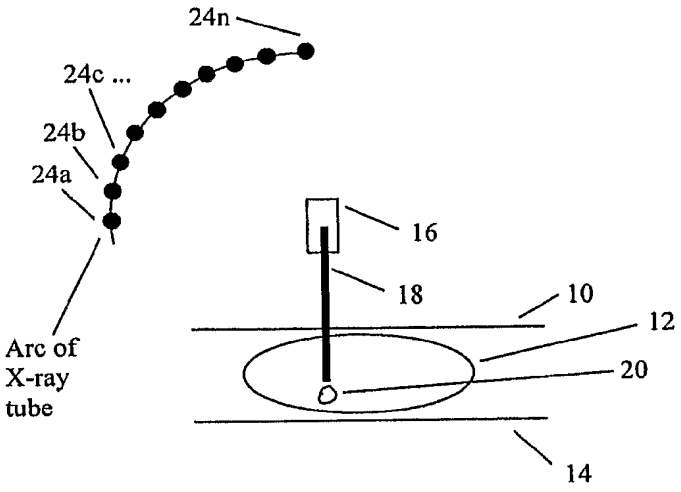
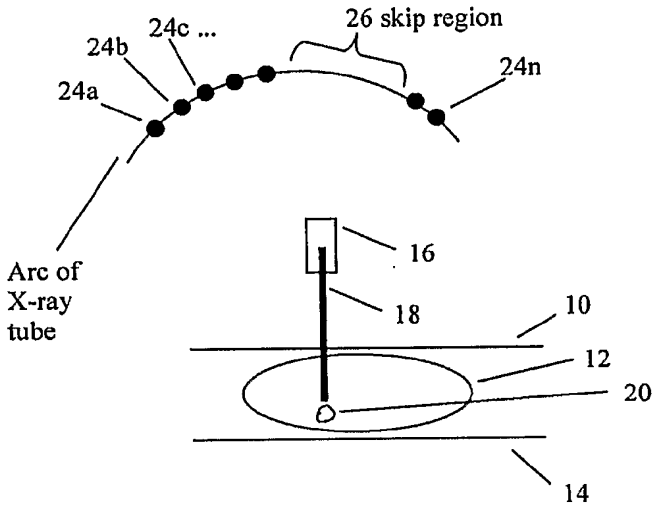


Fig. 5
System showing tomo scan skipping exposures at angles that would cause artifacts of stage in the image



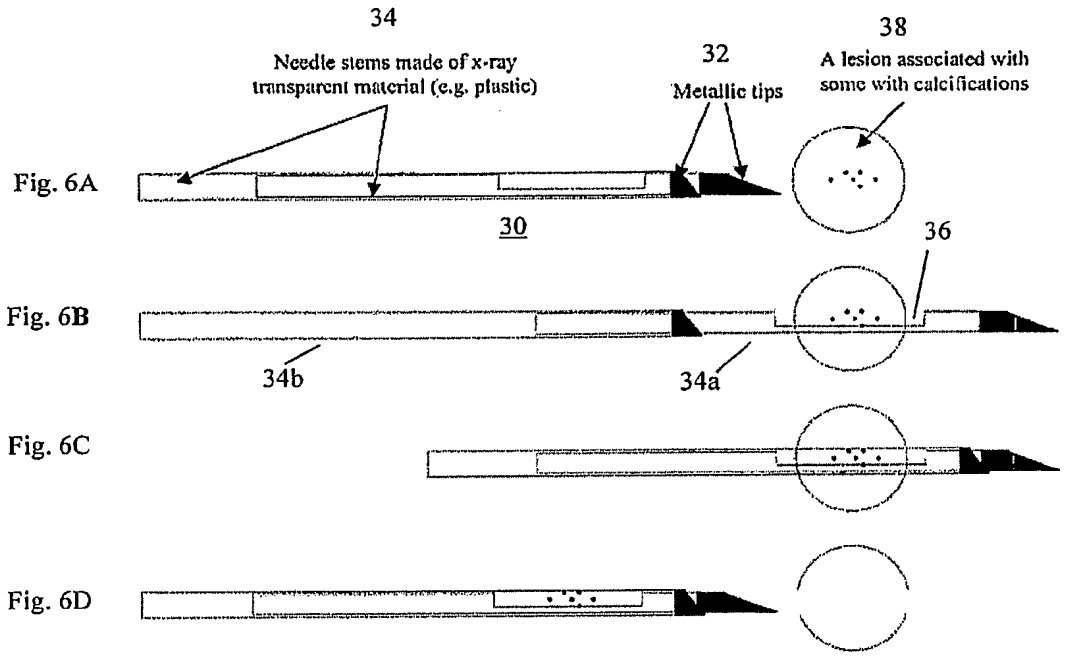


Figure 6 Illustration of biopsy needle with two radio-opaque tips and transparent body

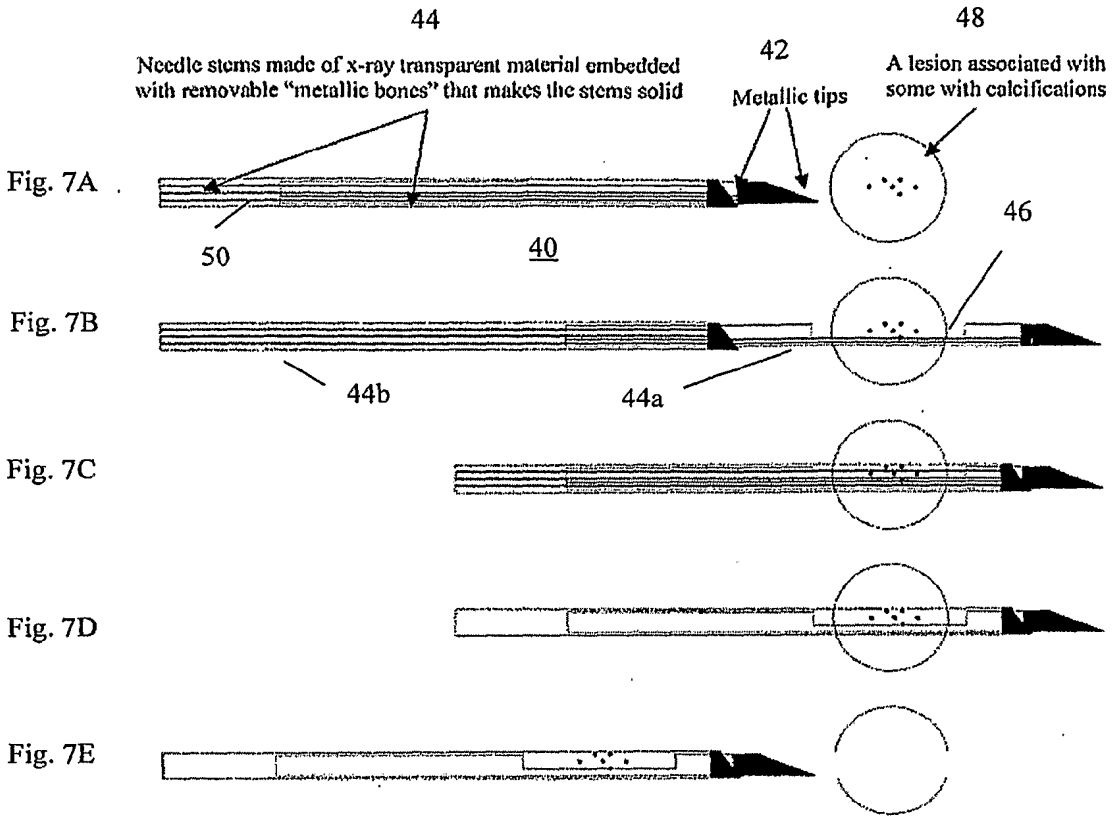


Figure 7 Illustration of biopsy needle with two radio-opaque tips and transparent body embedded with metallic stiffening rods

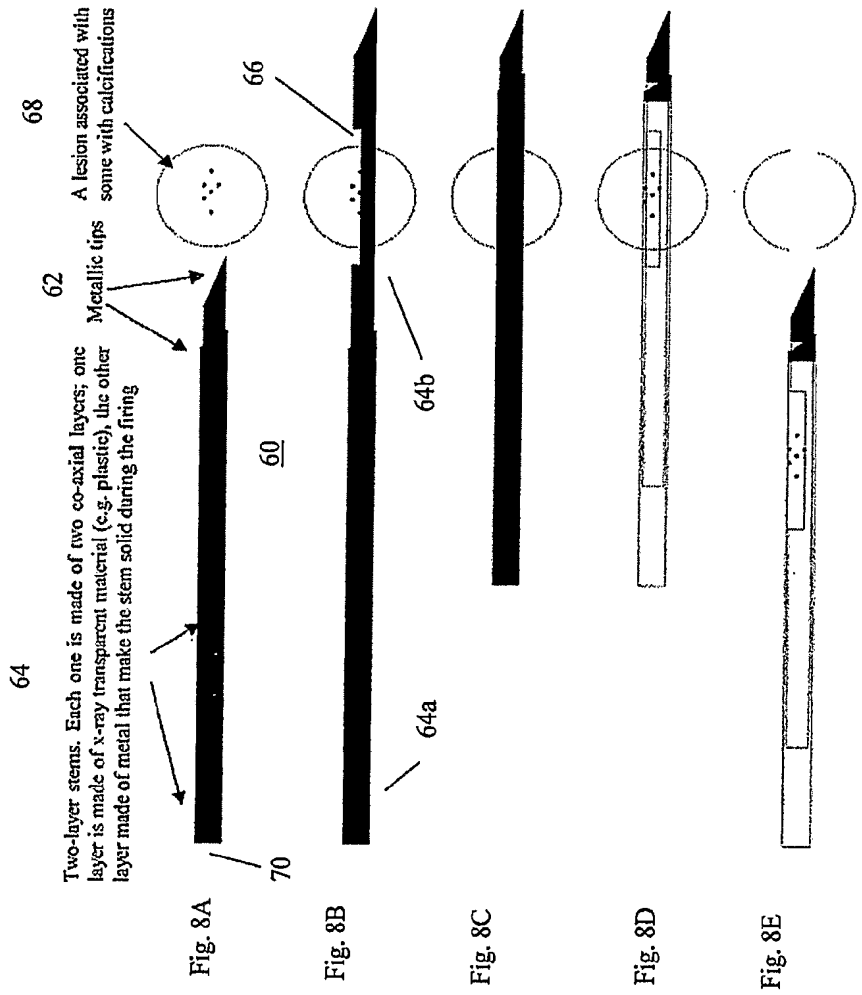


Figure 8 Illustration of biopsy needle with two radio-opaque tips and a coaxial layer, one of which is radio-opaque and the other radio-lucent.

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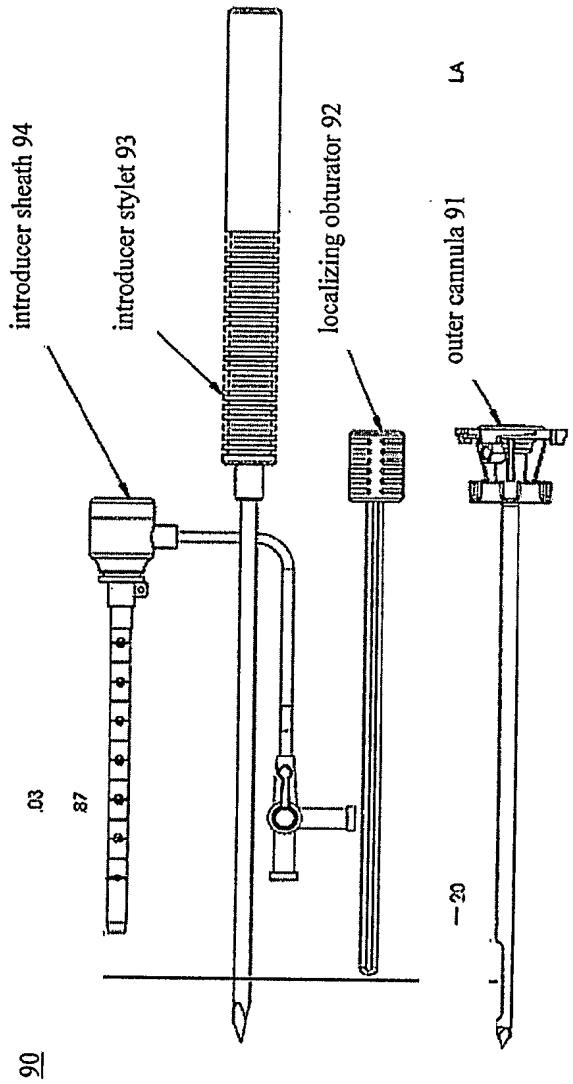
Fig. 9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introducer stylet 93
localizing obturator 92
outer cannula 91
LA
90
03
87
20

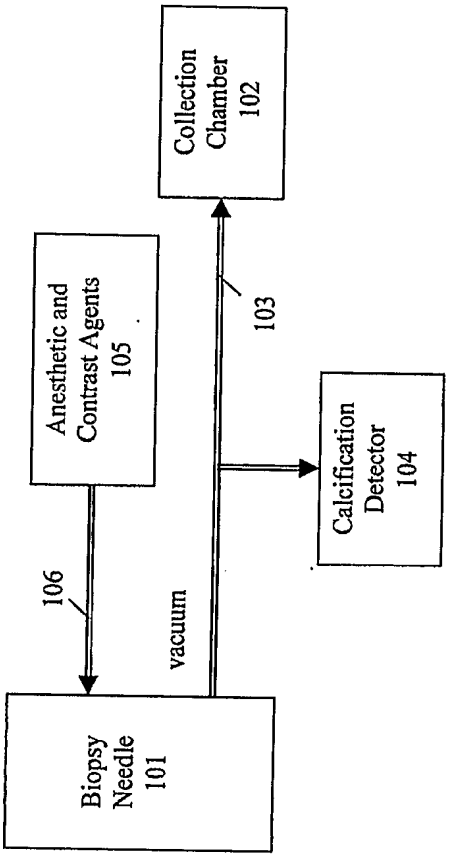
Collection Chamber 102
Anesthetic and Contrast Agents 105
103
Calcification Detector 104
106
vacuum
Biopsy Needle 101
100

Fig. 10

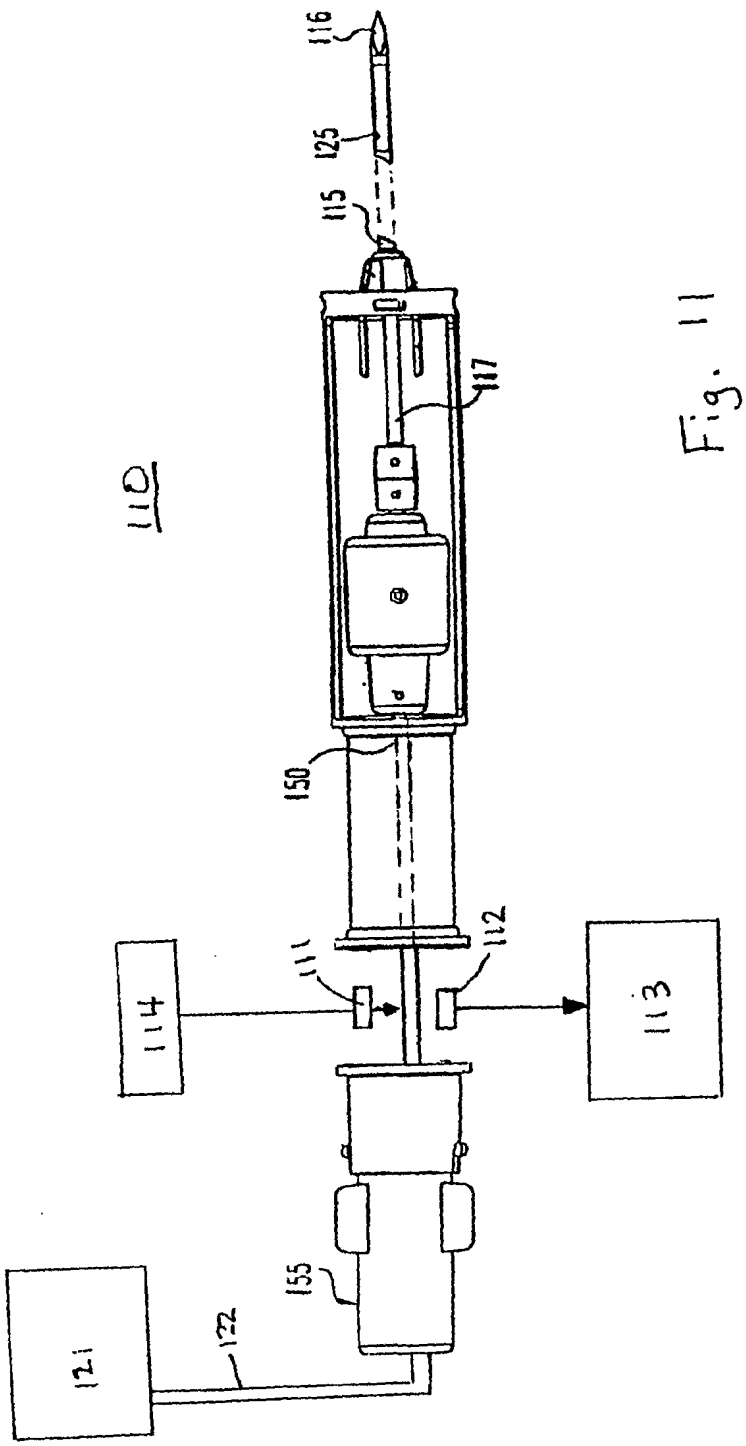

Fig. 11